GPS Surface Reflection for Ionosphere and Sea State Determination.

Dr. Stephen J. Katzberg
M.S. 328
NASA-Langley Research Center
Hampton, Virginia
phone: (757) 864-1970 fax: (757) 864-1975 email: s.j.katzberg@larc.nasa.gov

Mr. Lloyd A. Linstrom
Applied Physics Lab
11100 Johns Hopkins Road
Laurel, MD 20723
phone: (443) 778-3245 fax: (240) 228-6635 email: lloyd.linstrom@jhuapl.edu

Award Number: N00014-99-F-0311

LONG-TERM GOALS

In the past three to four years the recognition that GPS signals reflected from the earth's surface can yield useful geophysical information has led to aggressive and successful efforts to begin the exploitation of this phenomenon. Current research has demonstrated performance utilizing only the unencrypted C/A code at the L1 frequency of GPS. Information available when using both L1 and L2 is expected to enhance sea state and wind field retrievals and enable other important measurements. These enhancements will further improve performance of GPS as a powerful new tool for remote sensing from aircraft, balloon, and space platforms.

OBJECTIVES

The objectives of this research effort will be to quantify the capability of GPS receivers, using the full extent of the GPS L1-L2 signal structure, to remotely determine sea state and relative time delay from sea surface reflected signals. The accuracy of wind speed and direction retrievals will be both modeled and experimentally investigated. Model predictions for space-base performance will be made along with identification of required instrumentation enhancements to maximize performance.

APPROACH

The differences between the reflected signal at L1 and L2 will be modeled. This model will include a Kirchoff approximation diffraction version to retain the wavelength dependence and the statistical properties. The improvement in determination of gross delay (ionosphere application) and correlation power width (sea state/wind fields) will be determined. Cross-correlation of the L1 and L2 signals, both in complex form and mean square form, will be investigated. Matched filtering will be applied to those signals that can be shown to retain characteristics of the surface roughness. Inferences as to the surface correlation function and relative time delays (ionosphere application) will be studied. The ability to determine wind direction will be assessed to attempt to yield the full wind field, magnitude, and direction on the sea surface.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **GPS Surface Reflection for Ionosphere and Sea State Determination**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NASA-Langley Research Center,,M.S. 328,,Hampton,,VA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In the past three to four years the recognition that GPS signals reflected from the earth???s surface can yield useful geophysical information has led to aggressive and successful efforts to begin the exploita-tion of this phenomenon. Current research has demonstrated performance utilizing only the unen-crypted C/A code at the L1 frequency of GPS. Information available when using both L1 and L2 is ex-pected to enhance sea state and wind field retrievals and enable other important measurements. These enhancements will further improve performance of GPS as a powerful new tool for remote sensing from aircraft, balloon, and space platforms.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The types of receivers that might be employed for model verification and test of theoretical predictions are broadband sampling receivers that require post processing to extract correlation power versus delay for each of the various satellites and conventional P(Y) code receivers from companies such as Allen Osborne, Ashtech, Motorola, etc. A software GPS receiver has already been built by the Applied Physics Laboratory of Johns Hopkins University (JHU-APL); this receiver will be upgraded to accommodate the wider bandwidth of the P(Y) code. The data to be taken will require the encryption keys for the Y code.

A measurement campaign has been defined to produce the data products for evaluation. This includes the location of data takes, the *in situ* data required, coordinate instrumentation, the sea state, and other conditions needed and the logistics involved.

WORK COMPLETED

1. Theoretical studies were done to continue the theoretical foundation for the surface reflection phenomena. Models of wind direction effects have been extended beyond bivariate Gaussian versions by use of the Cox and Munk empirical formulations.

2. Final design of the GPS receiver for surface reflection research using both L1 and L2 frequencies was completed with breadboard in October 2000.

3. Fabrication and test of the GPS receiver board capable of recording direct and reflected signals was completed in March 2001. Y Code facility was demonstrated in April 2001, at which time signal acquisition at both L1 and L2 was demonstrated. The three boards were operational in July 2001.

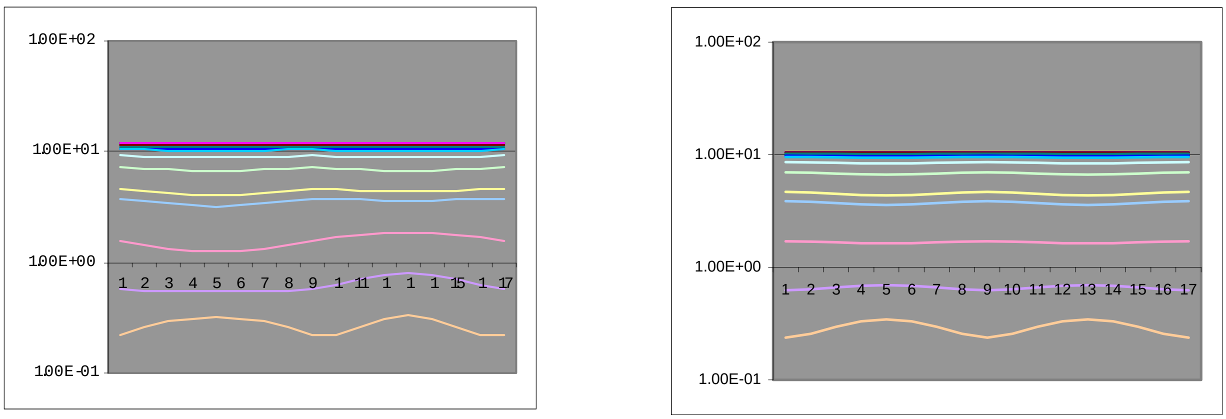
4. Aircraft integration was completed in July 2001 and first flights were accomplished on July 12, 13, 16, and 17. Analysis of data is currently under way with initial results presented later in this report.

Figure 1. Johns Hopkins Applied Physics Laboratory surface reflection receiver installed in light aircraft for first experimental flight series.

RESULTS

Theory

As mentioned above, modeling was done to use the Cox and Munk slope probability density to predict scattering. This density is based directly on empirical measurements while the Gaussian is only indirectly based on measurement. The Cox and Munk form exhibits a once per 360°-direction variation, unlike the Gaussian model. A comparison of the pure Gaussian with the Cox and Munk Gram-Charlier form is illustrated in Figure 2.



(a) **(b)**

Figure 2. Azimuth integrated scattering function using Cox and Munk PDF, (a) versus wind direction in 16 steps per 360° and Gaussian version (b) at 20 m/s, 45° elev.

P(Y)-Code Results

The objective of this element of the research project is to determine the utility of acquiring both GPS reflected signals, L1 and L2. These signals only have the same form for the P-Code signal since the C/A-code impressed on the carrier at L1 is not on the L2 signal. Among the topics being investigated are the similarity of the two signals, the use of the two signals to improve wind speed retrievals, the use of the two signals to determine relative delay between the two (for possible application at satellite altitudes), and the use of the P-Code signals to provide wind speed and direction at approximately 1/3 the altitude required for the C/A-Code.

Data from the flights was collected and then processed using the appropriate Y-Code encryption keys to extract power versus delay for the surface reflected signals. Both L1 and L2 yielded reflected signals. Two days were devoted to ocean reflection, with *in situ* data derived from the over-flights of NOAA buoy 44014 (Virginia Beach Buoy) located at 36.58 N 74.84 W (36°34'59"N 74°50'24"W).

Improvement in the mapping resolution of the integrated scattering function for P(Y)-Code compared to C/A code is apparent in Figures 3 through 6. The first figure represents previous results for power versus delay using the C/A code and indicates the very small change from a “lambda-squared” function from which wind speed determination must be made.

Figure 3. Flight path for one of buoy overpasses. Buoy is NOAA buoy number 44014 ("Virginia Beach Buoy") off southeast coast of Virginia.

The subsequent two figures represent the scattering function at L1 and L2 using the P(Y)-Code with its order of magnitude finer range cell (30 meters versus 300 meters). Wind speeds for these measurements were approximately 6.2 meters per second (one hour average) with sustained gusts to approximately 9.0 meters per second as reported by Virginia Beach Buoy.

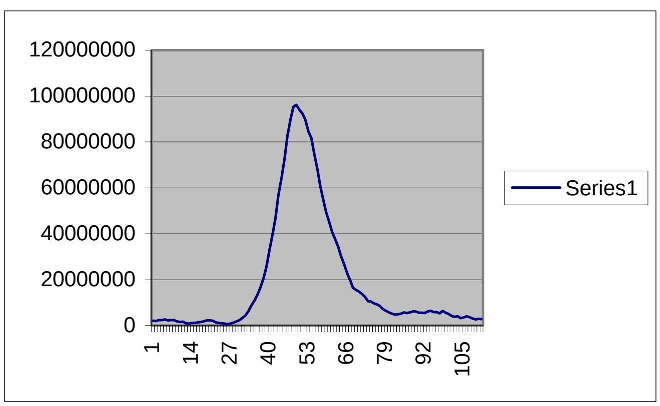


Figure 4. Power versus delay for C/A code for buoy overflights on July 17, 2001. Wind speeds were approximately 6 meters per second.

Initial data analysis indicates highly variable degrees of cross correlation between the two signals at L1 and L2. As can be seen from Figure 4 and Figure 5, the curves look similar, but are not identical. These data represent 41, one millisecond averages. Some samples processed show reasonable degrees of correlation, while many others do not.

What is more surprising is the lack of correlation between contiguous samples at the same frequency. That is, if a representative one-millisecond sample is cross-correlated by an adjacent one-millisecond sample, there appear to be highly variable results. The concept of a “frozen sea” consists of the assumption that the surface of the water can only change over time intervals of tens of milliseconds. In one millisecond, conversely, the sea is assumed not to change perceptibly. Taken together these introduce a condition known as “Rayleigh-fading.” Independent samples occur only after the sea surface evolves, or over time intervals of a few tens of milliseconds.

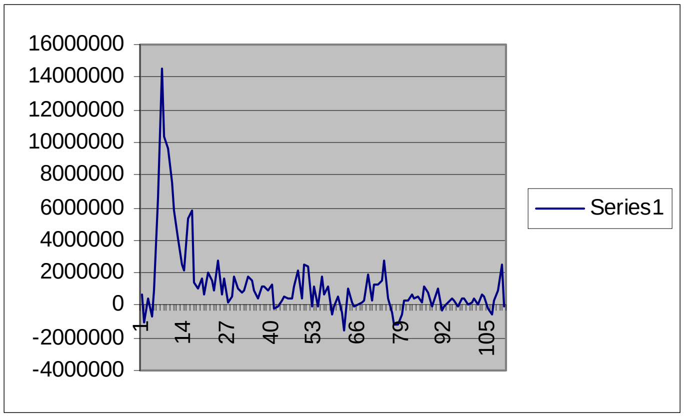


Figure 5. Power versus delay at L1 using P(Y)-Code on July 17, 2001. The increased resolution is apparent when compared to the C/A code above.

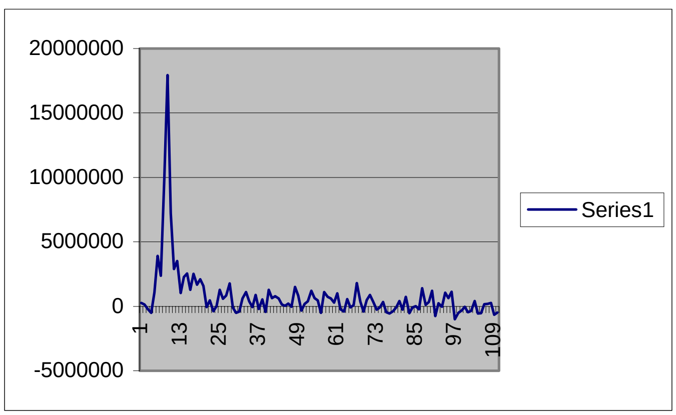


Figure 6. Power versus delay at L2 using P(Y)-Code on July 17, 2001.

IMPACT/APPLICATIONS

Operational, realtime avionics/displays of surface roughness, wind speed, and direction for littoral operations. Space remote sensing of surface wind fields in “piggy -back” mode.

TRANSITIONS

(In process)

RELATED PROJECTS

(Contact Principal Investigator)

PUBLICATIONS

Asher, M., G. Moore, and L. Linstrom, "Capture and Analysis of Reflected GPS Signals Using a Reconfigurable Wideband Recording System," ERIM International Conference Remote Sensing for Marine and Coast Environments, May 2000.

PATENTS

NASA Patent Disclosure LAR 16317-1, "Method For Determining Geophysical Parameters From Geostationary And Other Satellite Transmissions," by Stephen J. Katzberg, disclosed 6/25/01.